Forecasting the Climate Response to Volcanic Eruptions

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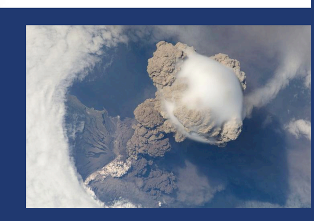

VOLCADEC

Introduction

The last major volcanic eruptions, the Agung in 1963, El Chichón in 1982 and Pinatubo in 1991, were each associated with a cooling of the troposphere that has been observed over large continental areas and over the western Pacific, the Indian Ocean and the southern Atlantic. Simultaneously, Eastern tropical Pacific temperatures increased due to prevailing El Niño conditions. Here we show that the pattern of these near-surface temperature anomalies is partly reproduced with decadal simulations of the EC-Earth model initialised with climate observations and forced with an estimate of the observed volcanic aerosol optical thickness. Sensitivity experiments highlight a cooling induced by the volcanic forcing, whereas El Niño events following the eruptions would have occurred even without volcanic eruptions. Focusing on the period 1961-2001, the main source of skill of this decadal forecast system during the first 2 years is related to the initialisation of the model. The contribution of the initialisation to the skill becomes smaller than the contribution related to the volcanic forcing after two years, the latter being substantial in the Western Pacific, the Indian Ocean and the Western Atlantic. Two simple protocols potentially usable to forecast the climate response to a new eruption are investigated: using the forcing of a past volcanic eruption with a similar magnitude, and applying a two-year exponential decay to the initial stratospheric aerosol load observed at the beginning of the forecast. This second protocol applied in retrospective forecasts allows to reproduce partially the skill related to the use of the observed forcing.

Method

To investigate the volcanic impact on the climate we performed various simulations with the EC-Earth (v2.3) ocean-atmosphere coupled model (Hazeleger et al., 2012):

Experiment	Start date (November)	Membs	Volcanic forcing	Initialisation from observation
Volc-Init	Each year over 1961-2001	5	Estimate from observed forcing.	Yes
Volc-NoInit	1850	12	Estimate from observed forcing	No
NoVolc-Init	Each year over: 1961-1964; 1980-1983; and 1989-1992	5	Stratospheric aerosol load set to background value (average of the forcing over 1850-2012)	Yes
IdealVolc1-Init			1-year exponential decay of the stratospheric aerosol load from the observed initial state	
IdealVolc2-Init			2-year exponential decay of the stratospheric aerosol load from the observed initial state	
SwitchVolc-Init	1963, 1982, 1991	5	Volcanic forcings switched between eruptions: 1963: Agung replaced by El Chichon; 1982: El Chichon replaced by Agung; 1991: Pinatubo replaced by el Chichon.	

References

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Near-surface Temperature Response to Volcanic Eruptions

The initialised forecasts that include the volcanic forcing (Volc-Init) reproduce the observed global cooling (fig. 1), while the one excluding the volcanic forcing (NoVolc-Init) does not reproduce the cooling that follows the volcanic eruptions.

The initialised forecasts (Volc-Init) includes both the volcanic forcing signal and the climate internal variability at the time of the eruption, while the non-initialised (Volc-NoInit) reflect only the volcanic signal.

The heterogeneous geographical pattern of the surface temperature response suggest that (i) the climate impact of volcanic eruptions can vary at the regional scale; (ii) 5 member- ensemble experiments may be too small to robustly detect the regional patterns of the volcanic imprint.

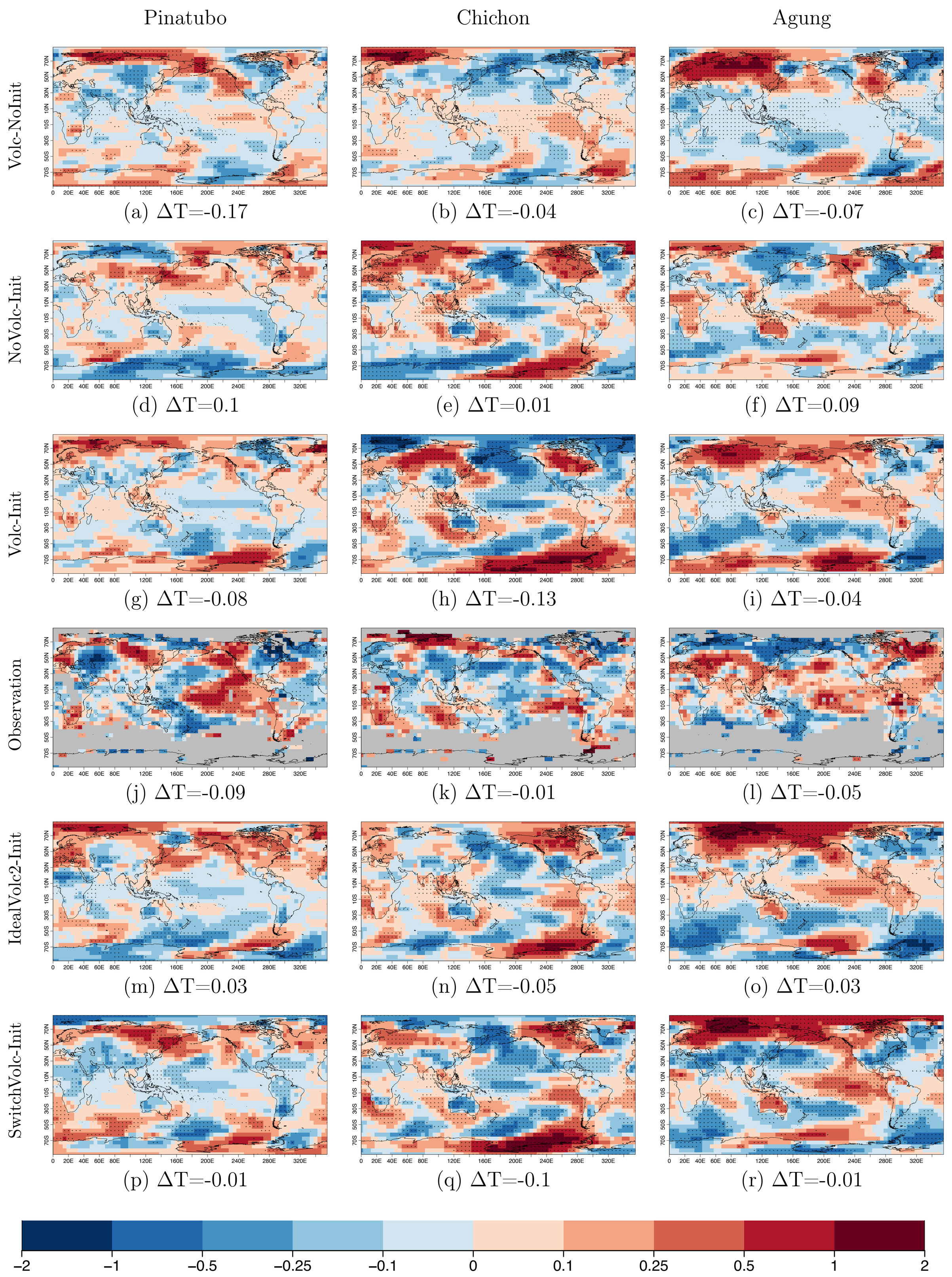
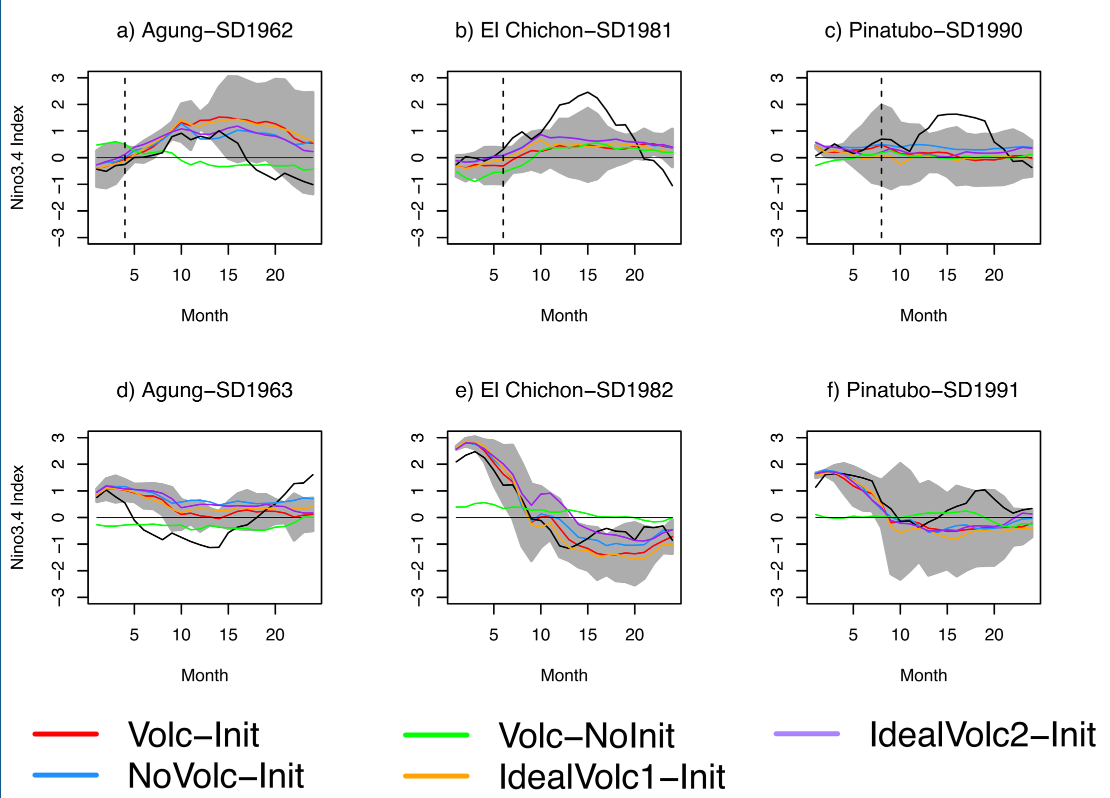


Figure 1: Three-year mean near-surface temperature anomaly (K) after the volcanic eruptions (computed from the month of January that follows the eruption, with respect to modelled or observed climatology over 1961-2001), after the Pinatubo (left), El Chichon (middle) and Agung (right) eruptions. The global mean temperature is shown below the maps.

An interesting feature is the lack of cooling, and sometimes a warming, simulated and observed in the Eastern Pacific following the volcanic eruptions. Millennium observations show an increase of the likelihood of El Niño events the first year following a volcanic eruption, consistent with several modelling studies (e.g. Maher et al., 2015).



The Niño3.4-index (fig. 2) shows that ENSO variations in the forecasts are probably due to the initialisation, suggesting that in EC-Earth2.3 the volcanic forcing may not have an impact on ENSO or it may not be detected due to the low signal-to-noise ratio.

Figure 2: Averaged SST anomaly (K) from 5S-5N and 170-120W (Niño3.4 region) with respect to a climatology computed over 1961-2001, used as an ENSO index in HadSST3 observations (black curve) and in EC-Earth simulations.

Forecast Skill of Volcanic Forcings

The forecast Volc-Init performs better the first two years (fig. 3a and 3c)., while Volc-NoInit has higher skill than the rest of the forecasts thereafter. This shows the improvement in skill in the first two years due to the initialisation and that beyond is dominated by the external forcings (c.f. Doblas-Reyes et. al., 2013).

The skill difference between the experiments is never significant in fig. 3a, probably because of the common global warming trends. Indeed, after removing the trends, the skill of the forecasts drop below the level of significance the third year (fig. 3b) and the differences between the experiments become statistically significant, showing the improvement of including volcanic forcing.

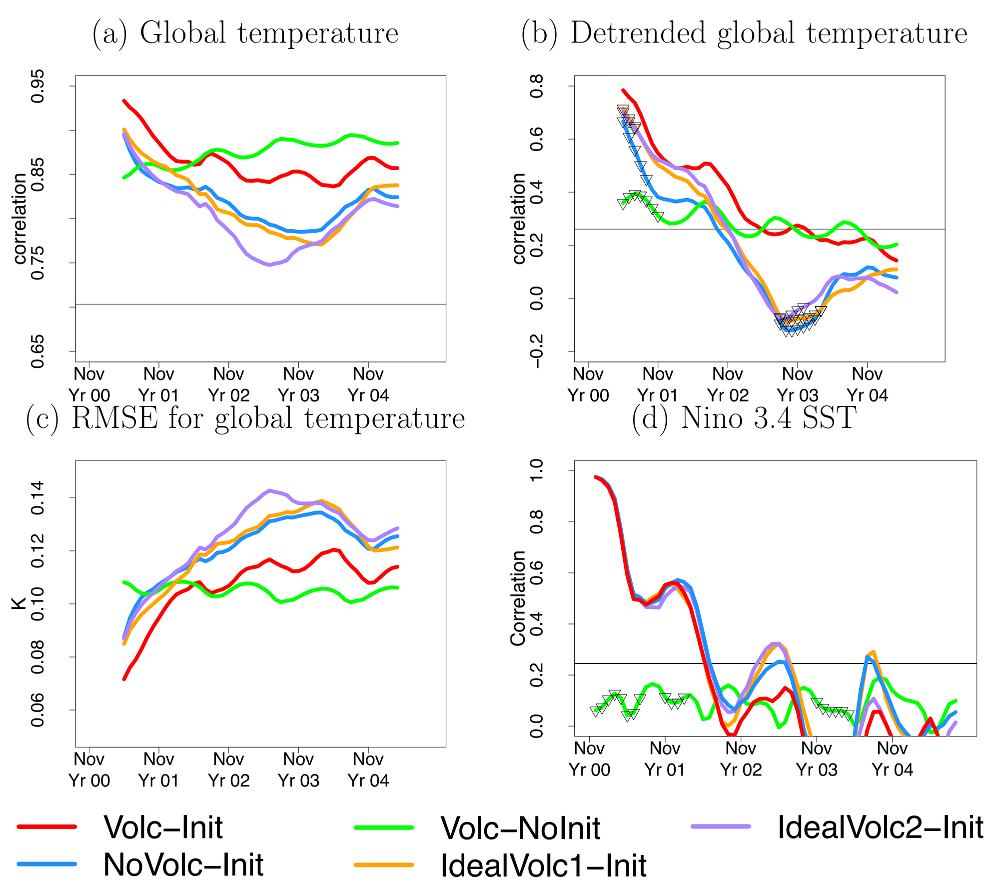
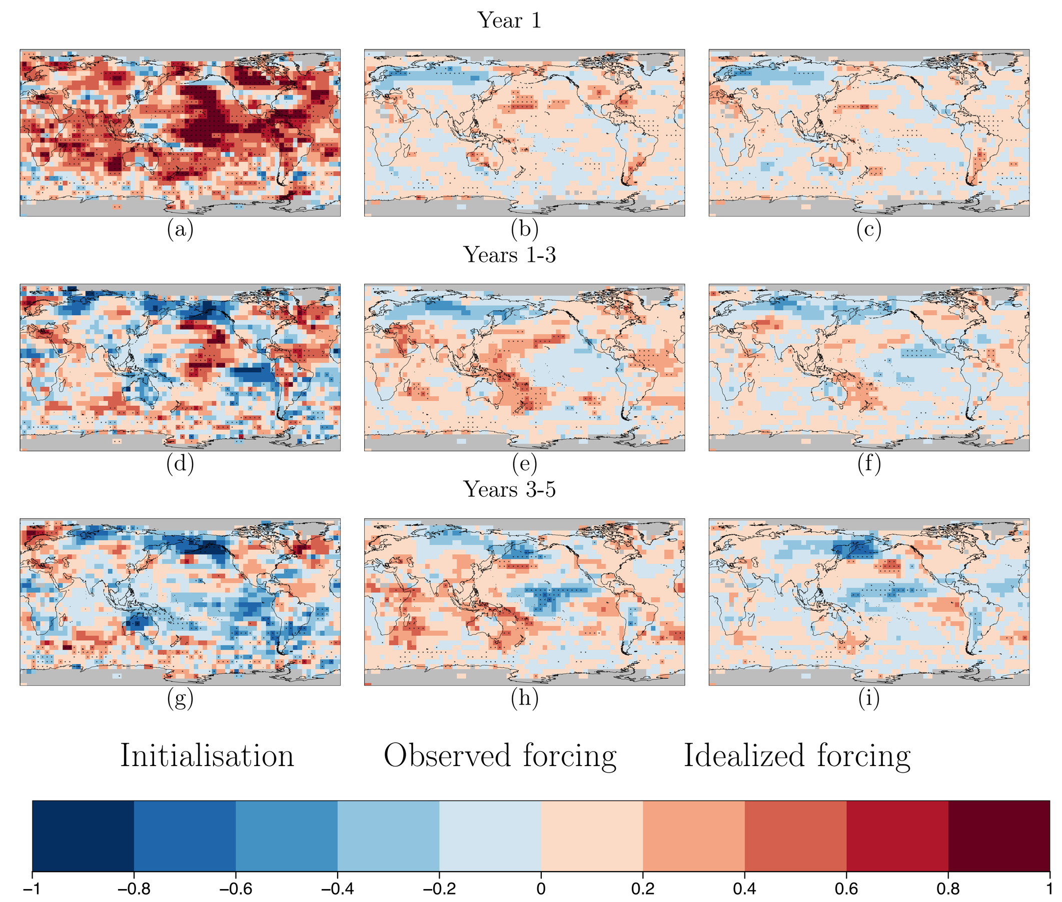


Figure 3: Skill of EC-Earth simulations (5-member mean) over the first five forecast years estimated from a comparison with HadCRUT4 observations: Correlation (a and b) and RMSE (c) of 12 months running mean anomalies of the global near-surface temperature; (d) Correlation of the SST in the Niño 3.4 region.

The ENSO skill is significant in our forecast in the first 18 months and is due to the initialisation, however it does not differ between the experiments that either include the volcanic forcing or not (fig. 3d).



Geographically, the first year of forecast is dominated by the initialisation, in particular in large areas of the Pacific, the tropical Atlantic and the Indian Ocean, but also in some areas of Northern America, Southern America and Africa. The contribution of the volcanic forcing is statistically significant in the Western Pacific for all the forecast years.

Figure 4: Contribution to the anomaly correlation coef. (ACC) for the first forecast year (Year 1, top), the average of the three first forecast years (Years 1-3, middle) and the average of the third, fourth and fifth forecast years (Years 3-5, bottom): from the initialisation (a, d and g), from the volcanic forcing based on observations, and from the idealized volcanic forcing based on a 2-year exponential decay (g, h and i).

Conclusions

- EC-Earth2.3 hindcasts initialised from observations and forced with an estimate of the observed volcanic aerosols reproduce a global cooling after the last three major volcanic eruptions that reaches a similar magnitude than the observed one. They reproduce also a regional cooling commonly observed for these eruptions in Western Pacific.
- EC-Earth2.3 model simulates a lack of cooling – or a slight warming - in the Niño3.4 region during three years after volcanic eruptions, but without a clear ENSO signal induced by the volcanic forcing, perhaps because more ensemble members are needed.
- EC-Earth2.3 hindcasts show significant skill in surface temperature the first two forecast years for the period 1961-2001 associated with the initialisation, then skill becomes dominated by the external forcings. The improvement in skill in hindcasts including the volcanic forcing are statistically significant only after detrending.
- Further research using larger ensemble experiments (~40 members) is needed to investigate and improve the prediction of the climatic response to volcanic eruptions, and in particular the dynamical response.